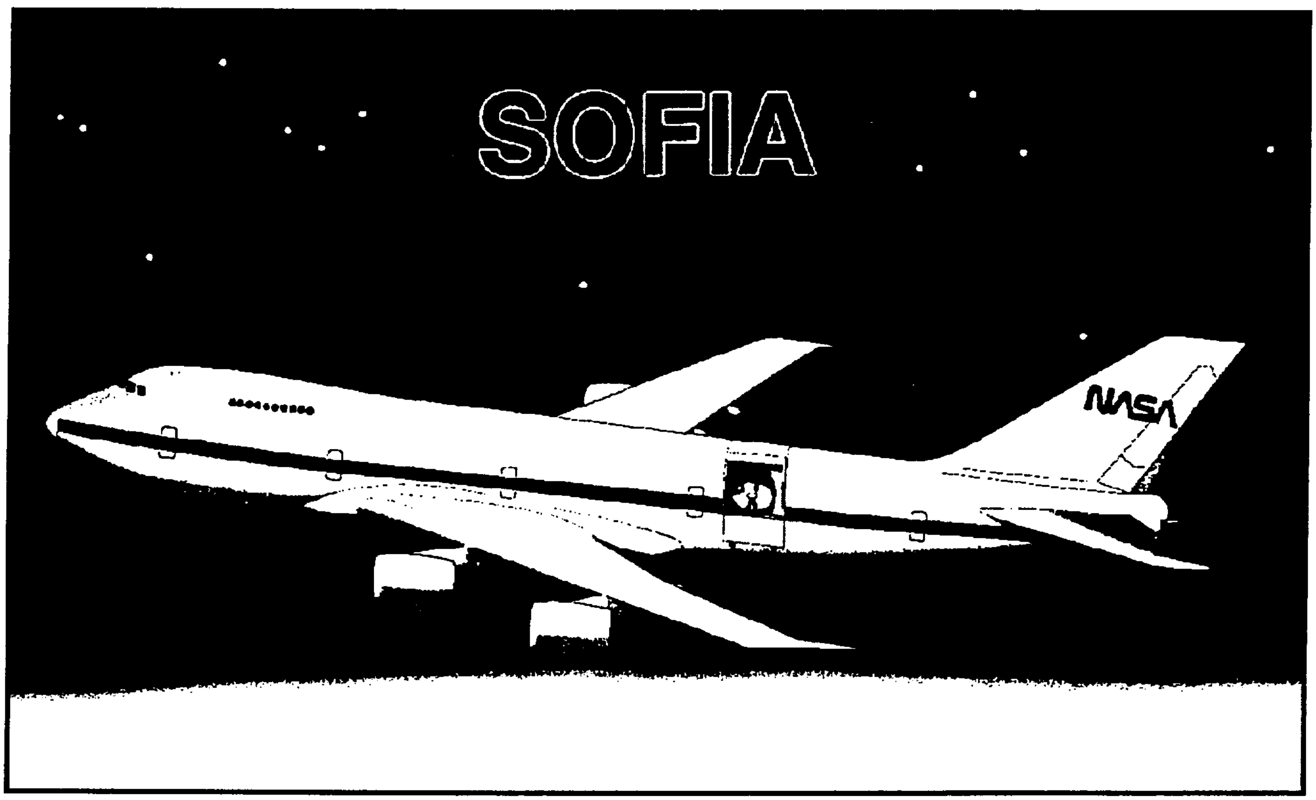
E-SYSTEMS

SOFIA

FINAL REPORT

AIRCRAFT SYSTEM, AFT TELESCOPE CAVITY CONFIGURATION - PHASE II



VOLUME I
EXECUTIVE SUMMARY
Report G5189.01.26

GREENVILLE DIVISION: P.O. BOX 6056: GREENVILLE, TEXAS 75403-6056: (903) 455-3450

16 Feb 1994

INTRODUCTION

This volume summarizes the tasks performed by E-Systems during Phase II of a study evaluating the structural modifications required to install the Stratospheric Observatory for Infrared Astronomy, SOFIA in the Boeing 747 airplane.

The SOFIA program is an important technology investment for America. SOFIA is structured with government, education and industry acting as pardners. SOFIA is a hi-tech program with hi-tech jobs for U.S. workers. Small and minority business will participate in the program.

The Boeing 747-200B was identified in Phase I of this study as the optimal platform for SOFIA. The cover illustrates the SOFIA concept which integrates a 2.5 meter infrared telescope with the 747 aircraft.

This report identifies an optimal structural modification concept for installation of the Infrared telescope and validates the concept by analysis of the static and dynamic characteristics of the modified structure.

STUDY GOALS

Define the structural modification necessary to restore the torsional rigidity required by the telescopes tracking and stabilizing system and to avoid any reduction of the airframes flutter margins.

Develop a detailed conceptual design for the pressure bulkhead which seals the pressurized cabin from the telescope cavity and which supports the telescope.

Perform dynamic structural analysis of the modified fuselage to predict its flutter characteristics

Perform dynamic assessment of the modified fuselage to predict its contribution to the dynamic characteristics of the telescope and its isolation system.

Determine the best process to assure the airworthiness of the SOFIA system while minimizing the cost of certification.

Assess the weight impact of the modification on the airplane's performance and its effect on the SOFIA mission.

STUDY FOCUS

AFT FUSELAGE MODIFICATION CONCEPT

Torsional rigidity is restored by the addition of longitudinal beams at the top and bottom of the telescope port, strengthening of stringers and doubling and tripling of skin thickness in the section surrounding the open port

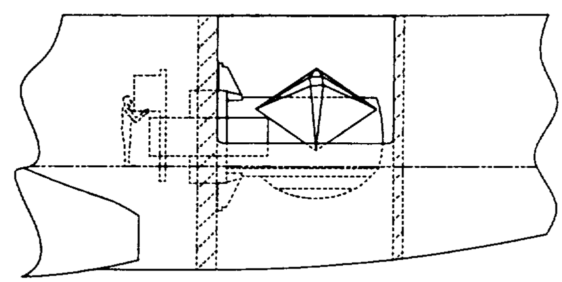


Figure 1. Telescope Mounting Concept

PRESSURE BULKHEAD TELESCOPE SUPPORT STRUCTURE

Conceptual design of a massive bulkhead, that serves the dual functions of a pressure bulkhead and mounting structure for the telescope. This design provides a basis for the structural analysis of this critical subsystem. Figure 1 is an illustration of the telescope mounting concept in which the telescope is suspended from the pressure bulkhead by concentric air bearing.

STRUCTURAL ANALYSIS OF CONCEPT

Finite Element (FE) analysis of the static and dynamic performance of the conceptual structure modification provides a basis for determining the additional weight of the required modifications. FE analysis also provides the tool for evaluating the dynamic interaction between airplane and telescope .

FE models were obtained from computer aided design (CAD) models of the modified structure. Analysis was conducted by classical analysis methods and by use of the dynamic capabilities of computerized FE analysis using the NASTRAN program.

DEFINE AND RECOMMEND AN AIRWORTHINESS VERIFICATION METHODOLOGY

Operation of a highly modified aircraft for specialized missions such as SOFIA, requires an analysis of the airworthiness of the structural modification, aircraft systems modification, and telescope system installation. Compliance with normal Federal Aviation Agency (FAA) Part 25 transport category certification rules to the maximum possible extent is recommended. Where the specialized nature of the modification or the aircraft operation is outside normal FAA certification guidelines, NASA in cooperation with industry will establish requirements and verification criteria.

The FAA has established an operational category for operation of military and civil aircraft used in specialized operations by government agencies. This category, identified as Public Aircraft, is recommended for operation of the SOFIA aircraft.

E-Systems operates an FAA approved repair and modification station for transport category airplanes. E-Systems also operates a number of aircraft maintainence facilities for government agencies through out the U.S.

MODIFICATION CONCEPTS

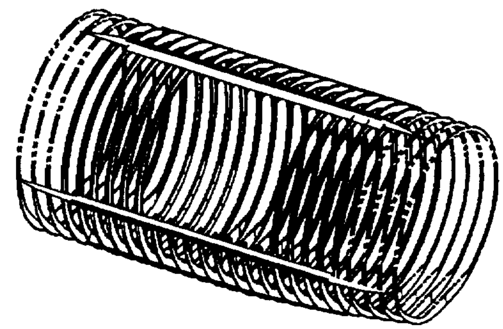


Figure 2. Telescope Cavity FE model

AFT FUSELAGE MODIFICATION

Figure 2 illustrates the telescope cavity and open port required by the 2.5 meter IR telescope. The open port extends lengthwise 180 inches between FS 1760 and FS 1940 and from stringer number 1 to number 23 , from top centerline to just below the window belt line, on the left side of the airplane.

PINNED END BULKHEAD

Figure 3 illustrates the preferred pinned end bulkhead attachment concept. This attachment method minimizes the deformation of the outer fuselage hull caused by flexure of the large bulkhead caused by pressure loads.

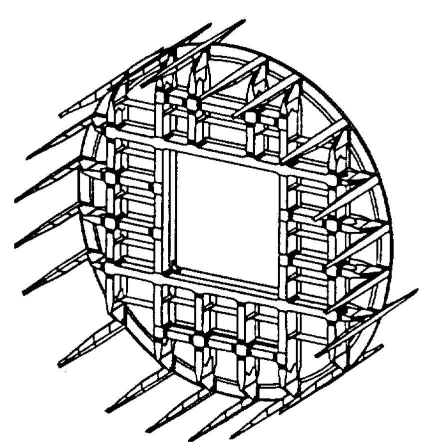


Figure 3. Pinned End Bulkhead Concept

FIXED END BULKHEAD

Figure 4 illustrates an alternative fixed end bulkhead attachment concept. This attachment method simplifies the physical attachments of the pressure bulkhead to the fuselage hull but requires additional strengthening of the hull to minimize the deformation of the outer fuselage hull caused by flexure of the large bulkhead caused by pressure loads.

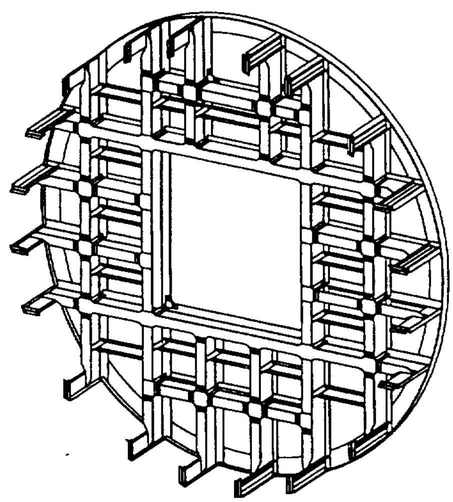


Figure 4. Fixed End Bulkhead Concept

STUDY CONCLUSIONS

BENDING AND TORSIONAL STIFFNESS IS CRITICAL FOR AIRCRAFT DYNAMICS

The over all torsional stiffness of the modified fuselage concept is calculated to be 10 percent stiffer than the unmodified B747 airplane. By maintaining a stiffness equal to or greater than the unmodified airplane the risk of reduced flutter margins is minimized.

All potential flutter modes including symmetric and anti-symmetric are well damped at Mach 0.9 with typical flutter margins of 100 percent, Vd to Vf.

LOAD REDISTRIBUTION AROUND TELESCOPE PORT CAN BE ACCOMPLISHED

Classical structural modification methods i.e., skin doublers and stringer reinforcement combined with upper and lower sill beam reinforcement extending forward and aft of the telescope port are capable of providing satisfactory strength and stiffness.

FLOOR STRUCTURE CAN BE REMOVED IN TELESCOPE BAY

Removal of the main cabin floor structure is required in the telescope bay to accommodate the large telescope optics. FE analysis was performed to verify that the floor structure could be removed with minimal impact to the airframe.

TELESCOPE'S MOUNTING DYNAMICS REQUIREMENTS CAN BE ACHIEVED

A parametric study of isolation system frequencies from 0.5 to 2.0 Hz revealed no coupling between the telescope and aircraft flutter critical modes.

To prevent magnification of telescope displacement at and above the lowest bending frequency of 1.55 Hertz requires the telescope isolation system be designed to respond at frequency below 1.09 Hertz.

AIRCRAFT DYNAMICS WILL BE MINIMALLY EFFECTED BY MODIFICATION

The flutter speed and resultant margin of safety were calculated for the unmodified and modified structure. No reduction in the normal aircraft flight envelope is required, the aircraft can be operated to standard performance manual limits.

STRUCTURAL MODIFICATION CAN BE ACCOMPLISHED WITHIN REQUIRED WEIGHT BUDGET.

Structural modifications are estimated to require a net addition of approximately 12,662 lb. to the airframe. With the addition of the telescope optics and mounting structure plus ancillary systems and payload the SOFIA zero fuel weight is estimated to be approximately 371,617 lb. At this weight the B747-200B aircraft is capable of carrying 376,836 lb. of fuel. This provides a mission range and endurance more than adequate for the SOFIA mission.

RECOMMENDATIONS

MAINTAIN TORSIONAL AND BENDING RIGIDITY OF THE UNMODIFIED AFT FUSELAGE

Design the modification to insure that the natural frequencies of the modified fuselage do not couple with the natural frequencies of the telescope or its suspension system.

Maximize torsional stiffness of the modified aft fuselage to minimize the complexity of alignment mechanisms for the telescope door system.

ACCEPT ADDITIONAL BENDING STIFFNESS

Structural strengthening necessary to maintain torsional rigidity results in fuselage bending rigidity greater than the unmodified fuselage. This increased stiffness has no negative effect on the aircraft's dynamic flutter margins

THE BOEING 747-200 IS PREFERED OVER THE B747-SP

The longer aft fuselage of the -200 permits a less complex modification because it need not involve the wing carry-through structure. Redistribution of the loads around the telescope port can be accomplished aft of the wing to fuselage interface and without involving the wing fairing.

Modification concept is applicable to the B747-SP but would entail additional cost and risk.

MINIMIZE HEIGHT OF TELESCOPE PORT

Height of the port is a critical parameter in terms of the difficulty of replacing the torsional stiffness of the fuselage. The height of the opening should be considered a critical design parameter since torsional siffness is very sensitive to the depth of the cutout required by the telescope's viewing port.

DESIGN OF THE TELESCOPE DOOR MUST BE INTEGRATED WITH THE AIRFRAME MODIFICATION

Interface between the door which seals the telescope bay on the ground and during the climb to altitude and the airframe modifications is defined as a critical interface. Integration of the door design and its aerodynamic fairing and the cavity aerodynamic and acoustics is recommended for the next phase of the development process.

This effort is dependent on the availability of wind tunnel results from the NASA Ames Reseach Center SOFIA model.